Return to the Ice Giants

Pre-Decadal study summary

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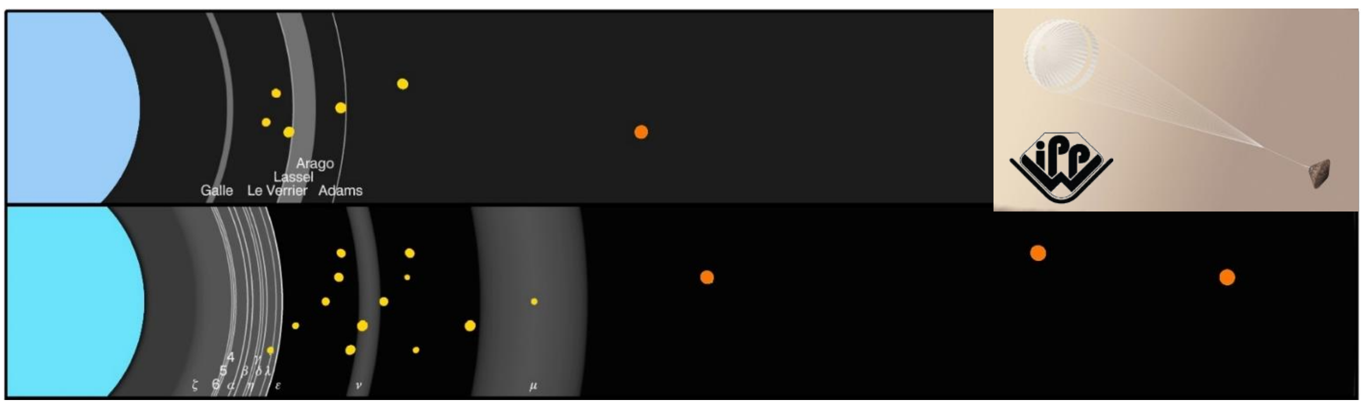


Study goal and objectives

Goal

- Assess science priorities and affordable mission concepts & options for exploration of the Ice Giant planets, Uranus and Neptune in preparation for the next Decadal Survey

Objectives

- Assess alternative architectures to determine the most compelling science mission(s) that can be feasibly performed within $2B ($FY15)

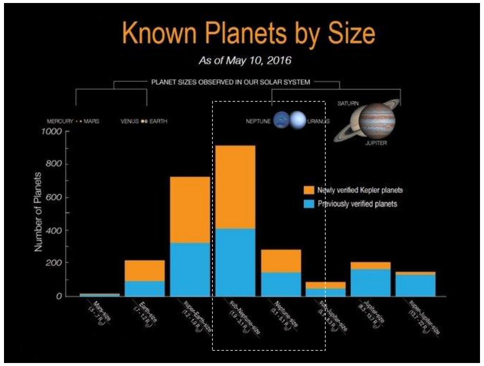
- Define mission concepts that can address science priorities based on what has been learned since the 2013–2022 Decadal Survey

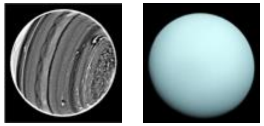
- Identify enabling/enhancing technologies

- Assess capabilities afforded by SLS

Why are Uranus and Neptune important?

- These relatively unexplored systems are fundamentally different from the gas giants and the terrestrial planets
  - Uranus and Neptune are ~65% water by mass (incl. methane, ammonia and other “ices”). Terrestrials are mostly rock; Jupiter/Saturn are ~85% H_2 and He
- Ice giants appear to be very common in our galaxy
- They challenge our understanding of how planetary systems form and evolve





Uranus in 2012 (left, Sromovsky et al. 2015) and 1986 (right, Voyager)

A dozen priority science objectives

Highest Priority

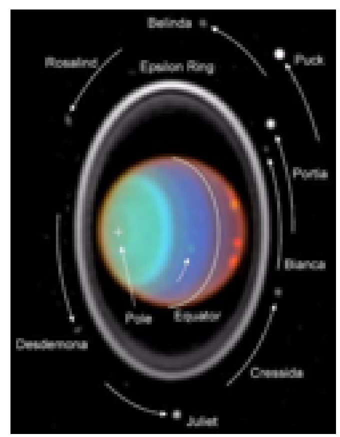
- Interior structure of the planet
- Bulk composition of the planet (including isotopes and noble gases)

Planetary Interior/Atmosphere

- Planetary dynamo
- Atmospheric heat balance
- Tropospheric 3-D flow

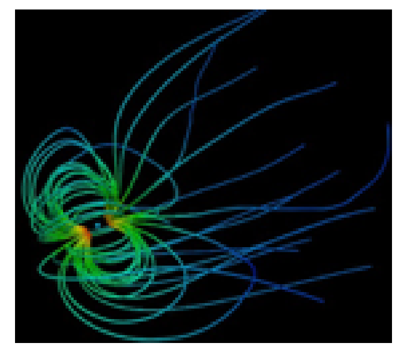
Rings/Satellites

- Internal structure of satellites
- Inventory of small moons
- Ring and satellite surface composition
- Ring structures and temporal variability
- Satellite shape and surface geology
- Triton’s atmosphere: origin, evolution, and dynamics



Magnetosphere

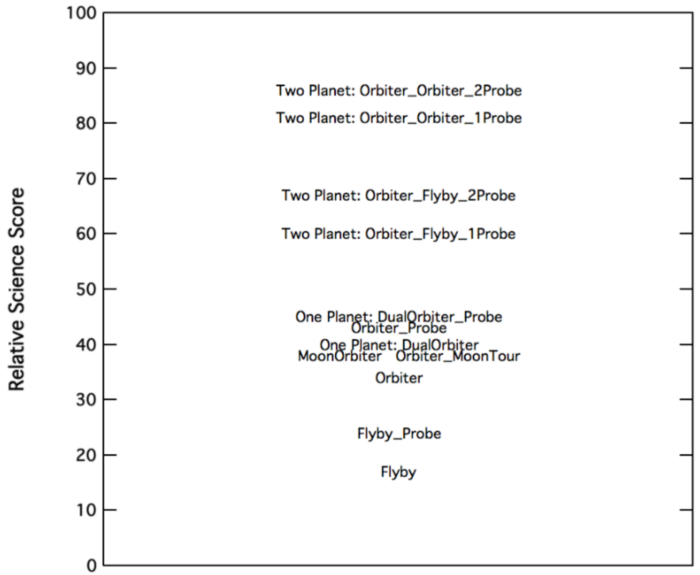
- Solar wind-magnetosphere-ionosphere interactions and plasma transport

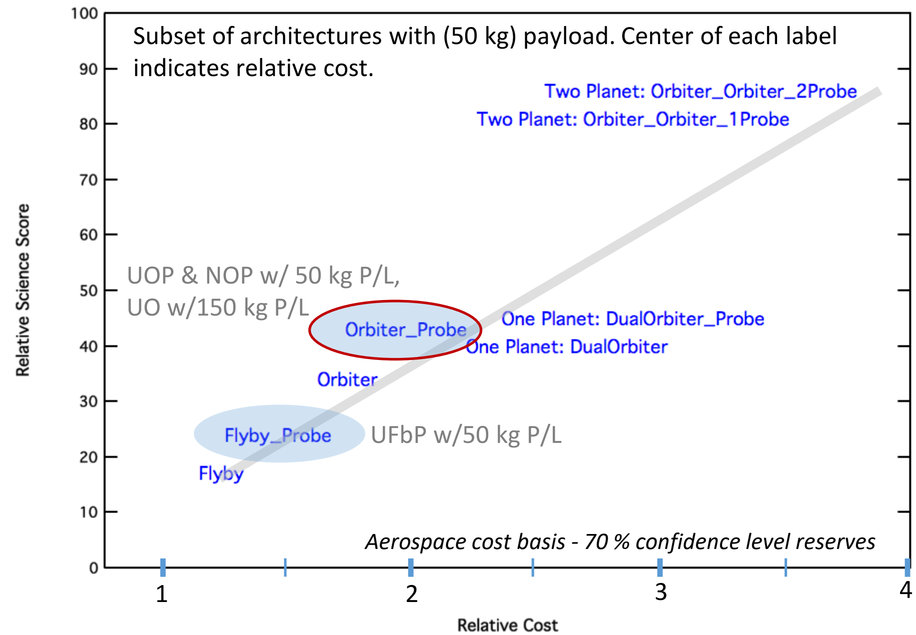


Alternative science architectures assessed; 4 concepts examined

- Wide range of architectures assessed; scored scientifically and costed
- Increasing investment in mission elements produces a correspondingly larger increase in science return.
- Adding second s/c to the other ice giant significantly enhances science return

- Flyby and single-planet orbiter w/probe concepts were costed to establish science-cost relationship
- Relative science score is approximately linear with mission cost, highlighting that we are not in a regime of diminishing returns
- Orbiter with probe is scientifically compelling and meets study cost target; additional payload elements increase science return and mission value

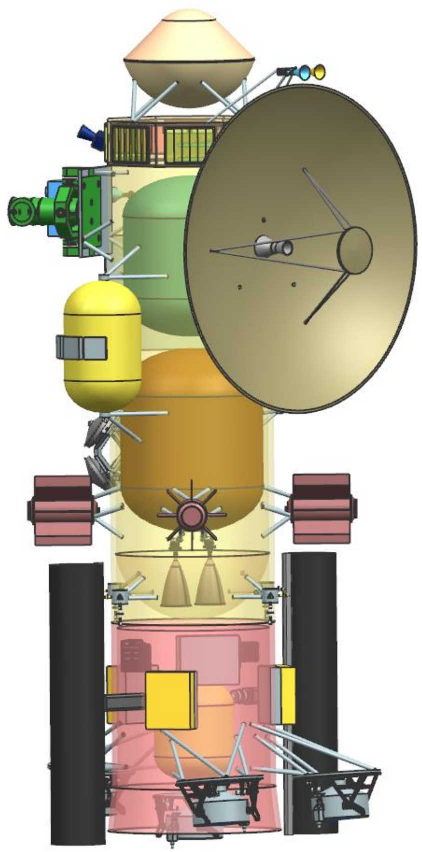




Common architectural building blocks

Flyby/Orbiter

- Avionics and structure
- Sensors and Telecom
- Chemical propulsion
- Radioisotope Power
- Payload accommodation
- SEP Stage
- Entry Probe



mission concept drawing

Payload Elements

NAC
Doppler Imager
Magnetometer

<50 kg

Vis/NIR imaging spectrometer
Radio and Plasma suite
Thermal IR
Mid-IR (Uranus) or UV (Neptune) spectrometer

~90 kg

WAC
USO
Energetic Neutral Atoms
Dust detector
Langmuir probe
Mwave sounder/Mass spec

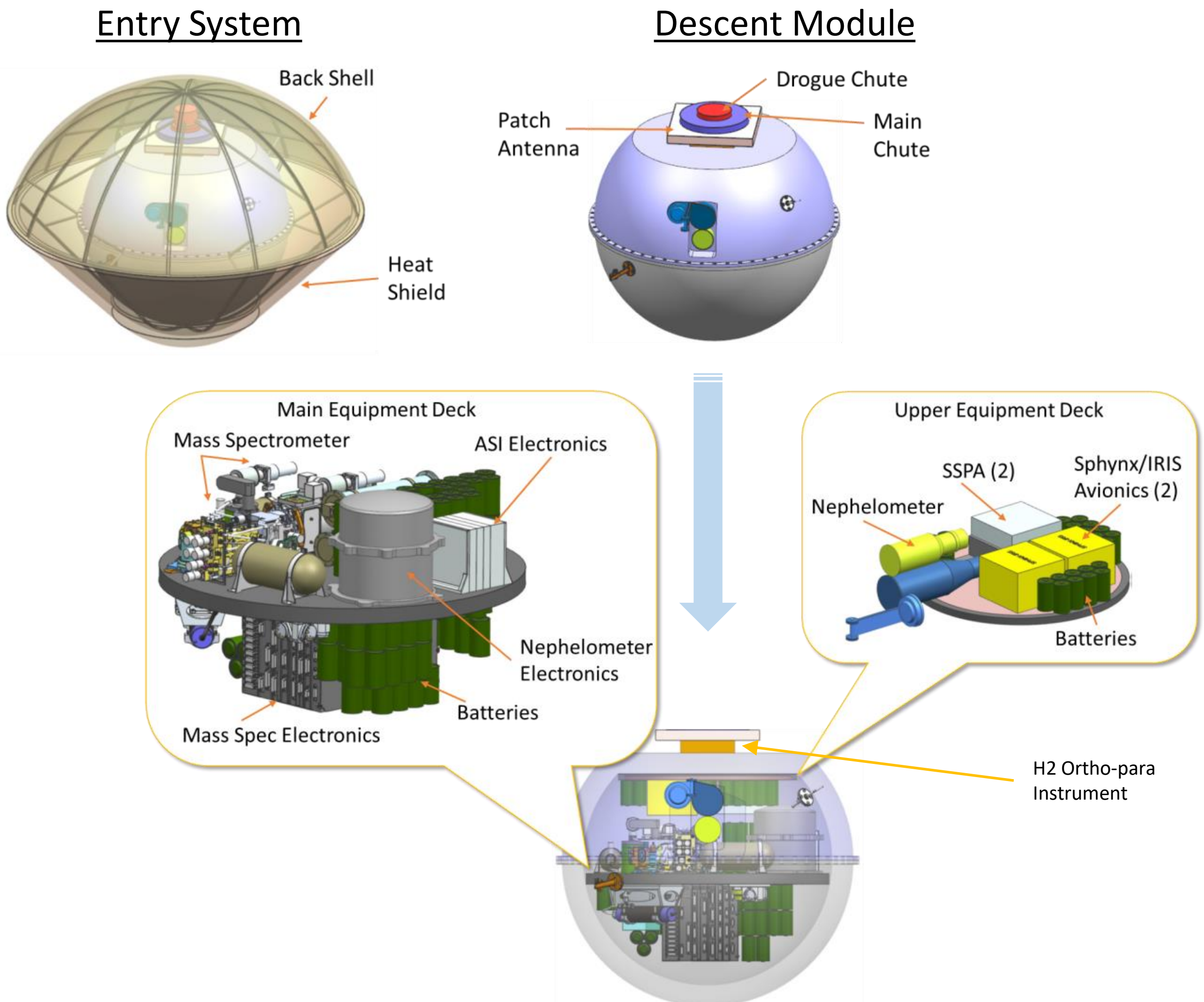
~150 kg

Common probe concept

- Vented probe; 45 deg sphere-cone
- Redundant Avionics
- Redundant UHF telecom relay
- Redundant Power Electronics
- Primary batteries, 1.0 kW-hr EOM
- RHU heating, passive cooling
- HEEET Heatshield, Backshell
- Parachutes

Descent Module: 174 kg
Entry System: 147 kg
Total Entry Mass: 321 kg

mission concept drawing



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Interplanetary travel (19-30 AU)

- Launch interval studied: [2024 – 2037]
- Total mission duration < 15 years including at least 2 years of science
- Tens of thousands of trajectories to both planets examined

Launch Vehicles	Interplanetary Trajectory	Gravity Assist (up to 4 per Traj.)	Target Bodies	SEP Power	EP Engines	Orbit Insertion
• Atlas V • Delta-IV Heavy • SLS-1B	• Chemical + DSM + GA • SEP + GA • REP + GA • Dual Spacecraft	• Venus • Earth • Mars • Jupiter • Saturn	• Uranus • Neptune	• 15 kW • 25 kW • 35 kW	• NEXT 1+1 (SEP) • NEXT 2+1 (SEP) • NEXT 3+1 (SEP) • XIPS (REP)	• Chemical (Bi-Prop) • Chemical (cryo) • REP • Aerocapture

Falcon heavy was not considered in the original trade space because detailed performance numbers were not available at that time. While estimates predict that the performance of Falcon Heavy for the mission concepts studied would be comparable to the Delta IVH, published data will tell.

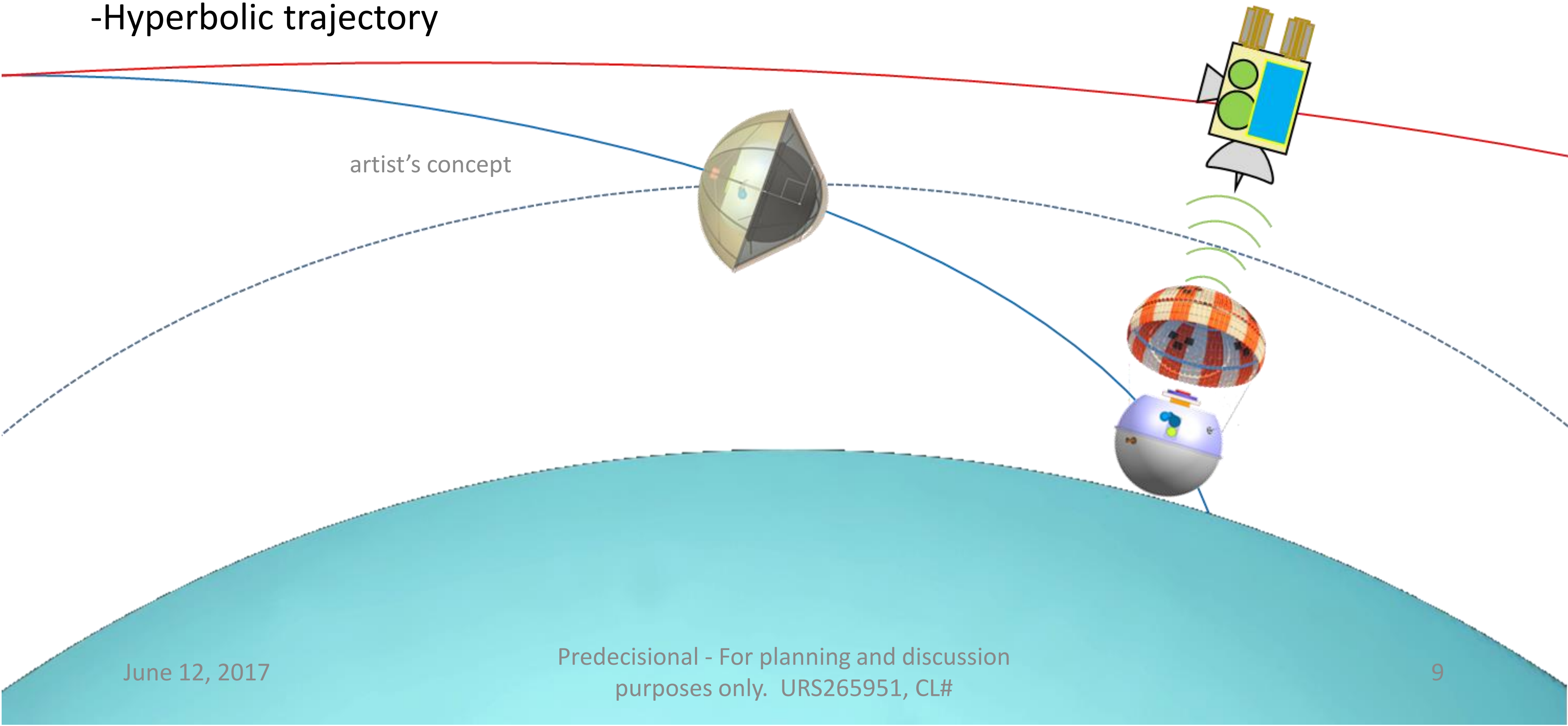
- Interplanetary flight times range from 6 – 12 yrs (Uranus); 8 – 13 yrs (Neptune)
- Optimal launch opportunities 2029-2032 use Jupiter gravity assist
  - Missions to Uranus via Saturn are possible through mid-2028; JGA takes over in the 2030s
  - No Saturn options exist for Neptune
- Chemical trajectories would deliver orbiter to Uranus in < 12 years; Atlas V
- SEP and/or SLS would be required to achieve <13 year transfer to Neptune

Probe concept of operations

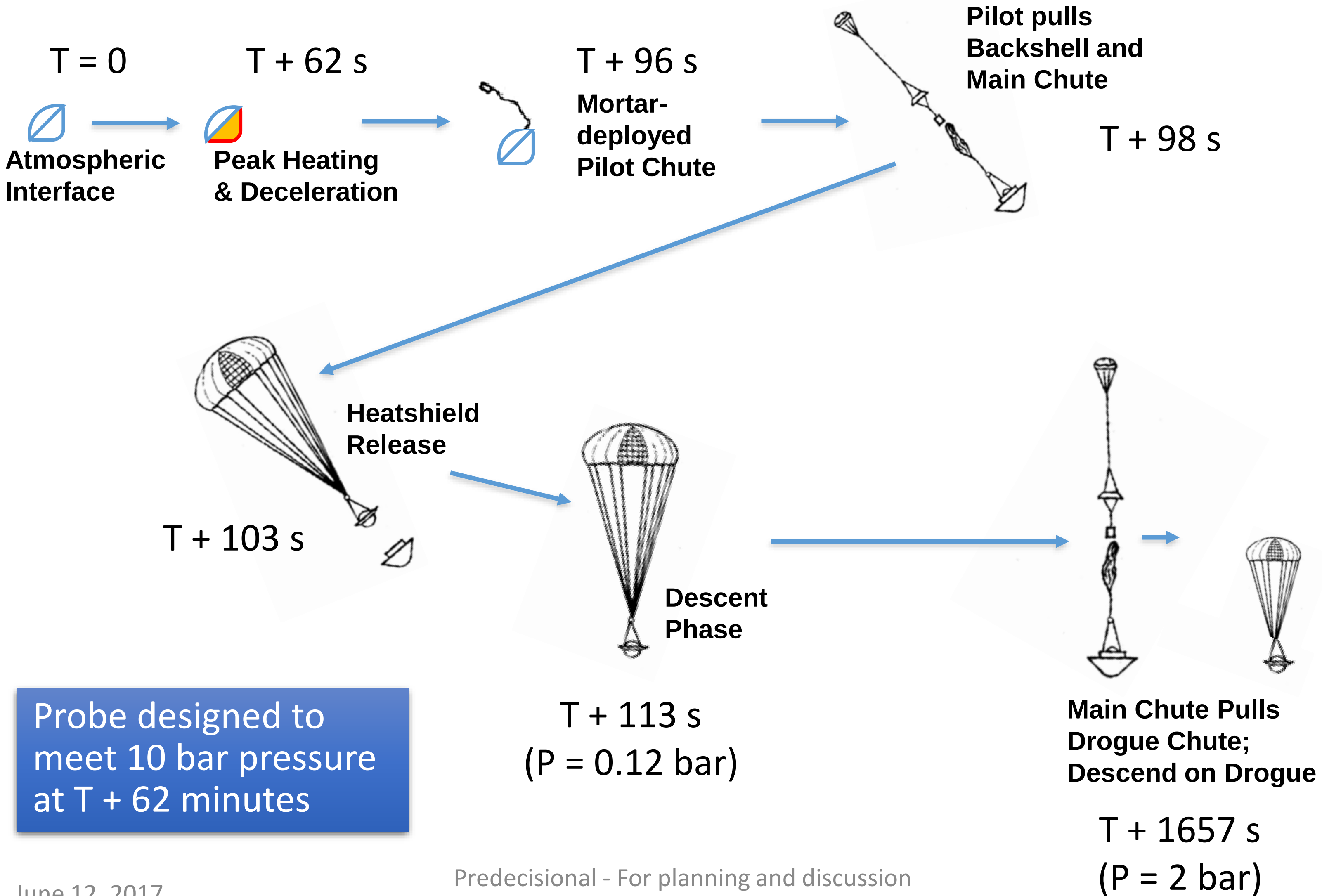
Release:
-60 days prior to entry
-Spin stable
-RHU heating
-Hyperbolic trajectory

Entry (Uranus/Neptune):
-Entry V = 23.5/24.1 km/s
-FP Angle = -30/-20 deg

Crosslink to Orbiter:
-Duration: ~1 hr
-Max Range: <100k km
-Data up: ~15 Mbit



Uranus entry scenario
(Artist's concept)

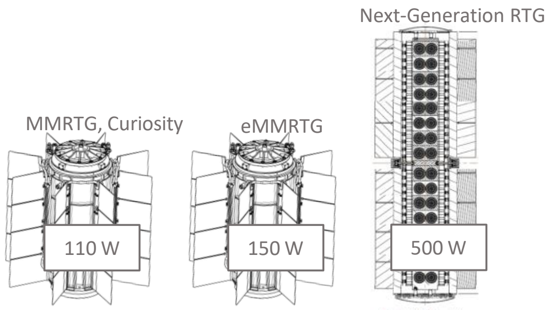


Probe designed to meet 10 bar pressure at T + 62 minutes

Technology considerations

- Conceptual and in development -

- In Space Transportation
    - Aerocapture
    - LOX-LH2 chemical propulsion
    - Radioisotope Electric Propulsion
- Optical communications
- Small satellites (100-400 kg), CubeSats
- Advanced Radioisotope Power
    - Proposed eMMRTG (ENABLING)
    - Next Gen RTG concept; 500 We
    - High Power Stirling Radioisotope Generator (HPSRG) concepts
- HEEET thermal protection system (ENABLING)
- Giant planet doppler imager (ENABLING)

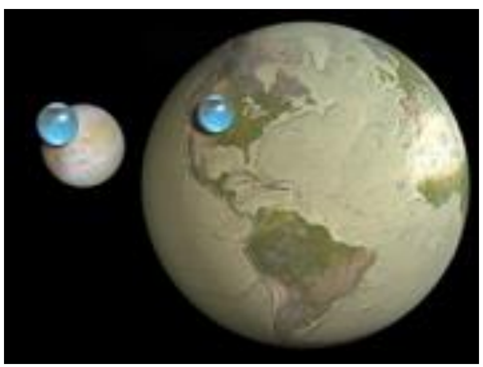


Primary study findings

- A Uranus orbiter with probe, launching near 2030, remains the highest priority Ice Giant concept; target payload elements in the 90-150 kg set
- Two-planet, two-spacecraft mission options are highly valuable scientifically at proportionally higher cost, yet less than the cost of two independent missions
- International collaboration presents opportunity to maximize science return while minimizing cost to each partner; best use of resources
- A follow-on NASA-ESA mission study should be performed, using refined programmatic ground-rules, to better define the concept likely to fly

Return to the Ice Giants in 2030?

- Opportunity to engage planetary, heliophysics and exoplanet scientists to advance humankind's understanding of our Solar System, exoplanetary systems, and planetary formation and evolution
- Timing provides opportunity to map the northern hemispheres of Uranian satellites, and sample unique solar wind and magnetosphere geometries
- No low TRL technology would be required



- Affordable international cost-share options are viable
- Accomplishes 3rd Flagship mission recommended by the 2013-2022 Planetary Science Decadal Survey

Supplemental

Mission study team –
Chartered by NASA; included ESA

NASA Interface: Curt Niebur

ESA Interface: Luigi Colangeli

Study Lead: John Elliott

JPL Study Manager: Kim Reh

JPL Mission Concept Team

Other Organizations
Langley Research Center (TPS)
Ames Research Center (TPS)
Purdue University (mission design)
Aerospace Corp. (ICE)

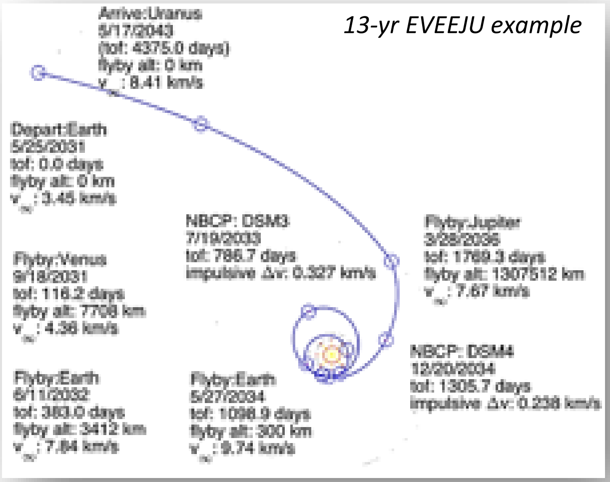
Science Definition Team: Co-Chairs: M. Hofstadter, A. Simon

Sushil Atreya (U Mich.)
Donald Banfield (Cornell)
Jonathan Fortnzey (UCSC)
Alexander Hayzes (Cornell)
Matthew Hedman (U Idaho)
George Hospodarsky (U Iowa)
Kathleen Mandt (SwRI)
Mark Showalter (SETI Inst.)
Krista Soderlund (Univ. Texas)
Elizabeth Turtle (APL)

ESA members
Adam Masters (Imp. College)
Diego Turrini (INAF-IAPS/UDA)

Mission design takeaways

- Optimal <u>launch</u> opportunities to Uranus & Neptune in 2029-2032 use Jupiter gravity assist
    - Missions to Uranus via Saturn are possible through mid-2028; JGA takes over in the 2030s
    - No such mission options (via Saturn) exist for Neptune
    - Launches are possible any year
- Chemical <u>trajectories</u> would deliver 1500 kg orbiter to Uranus in < 12 years using Atlas V
    - Delta-IV Heavy (F-Heavy similar) can reduce interplanetary flight time by 1.5 years
- No chemical trajectories exist for delivering a flagship class orbiter to Neptune in < 13 years using Atlas V or Delta-IV Heavy launch vehicles
    - SLS or longer flight times would be needed.
- SEP would enable a flagship orbiter to Neptune in 12-13 years
    - Implemented as separable stage to minimize propellant required for insertion
- Orbit insertion ΔV at both Uranus and Neptune is high
    - Neptune: 2.3-3.5 km/s
    - Uranus: 1.5-2.5 km/s



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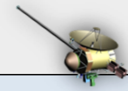
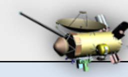
Concept summary

Highest Priority Concept: UOw/P; >90 kg payload

				
Case Description	Neptune **Orbiter** with **probe**; <50 kg science payload SEP stage for inner SS	Uranus **Flyby** with **probe** ; <50 kg science payload Chemical prop.	Uranus **Orbiter** with **probe**; <50 kg science payload Chemical prop.	Uranus **Orbiter** (no probe); ~150 kg science payload Chemical prop.
Science	Highest priority plus additional system science (rings, sats, magnetospheres)	Highest priority science (interior structure and composition)	Highest priority plus additional system science (rings, sats, magnetospheres)	All remote sensing objectives
Payload	3 instruments† + atmospheric probe	3 instruments† + atmospheric probe	3 instruments† + atmospheric probe	15 instruments‡
Payload Mass MEV (kg)	45	45	45	170
Launch Mass (kg)	7365	1524	4345	4717
Flight Time (yr)	2030/13	2030/10	2031/12	2031/12
Time in Orbit(yr)	2	Flyby	3	3
Total Mission Length (yr)	15	10	15	15
Baselined RPS/EOM Pwr	4 eMMRTGs/ 376W	4 eMMRTGs/ 425W	4 eMMRTGs/ 376W	5 eMMRTGs/ 470W
LV case	Delta IVH + 25 kW SEP	Atlas V 541	Atlas V 551	Atlas V 551
Total Mission Cost ($M) Team X/Aerospace	1971/2280	1493/1643	1700/1993	1985/2321

†includes Narrow Angle Camera, Doppler Imager, Magnetometer
‡includes Narrow Angle Camera, Doppler Imager, Magnetometer, Vis-NIR Mapping Spec., Mid-IR Spec., UV Imaging Spec., Plasma Suite, Thermal IR, Energetic Neutral Atoms, Dust Detector, Langmuir Probe, Microwave Sounder, Wide Angle Camera
**Includes cost of proposed eMMRTGs, NEPA/LA, and standard minimal operations, LV cost not included.*

- Neptune costs ~$300M more than Uranus for comparable science return (due to SEP stage)
- Uranus orbiter with probe is estimated to be in the range of $1.7 to $2.6B depending on orbiter payload (50-150 kg range) and reserve posture

Capabilities afforded by SLS

All single-planet mission concepts studied are achievable with existing ELVs, however,

SLS could provide enhancing benefits:

- Increases deliverable mass and lowers flight time by 3 to 4 years
- Enables chemical Neptune mission in 11.5 yrs
- Enables 2-spacecraft mission with single launch
- Increases launch opportunities

When combined with aerocapture, SLS would enable reduced flight times for both Uranus (< 5 years) and Neptune (< 7 years)